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Transparent scientific usage as the key to success of the Virtual Observatory

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Abstract. Nowadays, Virtual Observatory standards, resources, and services became powerful enough to help astronomers making real science on everyday basis. The key to the VO success is its entire transparency for a scientific user. This allows an astronomer to combine "online" VO-enabled parts with "offline" research stages including dedicated data processing and analysis, observations, numerical simulations; and helps to overpass one of the major issues that most present-day VO studies do not go further than data mining. Here we will present three VO-powered research projects combining VO and non-VO blocks, all of them resulted in peer-reviewed publications.

1. Introduction

The Virtual Observatory is a realization of an e-Science concept in astronomy. It forms a virtual environment aimed at facilitating astronomical research and increasing scientific output of data by providing transparent access to its resources including catalogues, databases, archives, data visualization, processing and analysis tools. There are conceptual similarities between the idea of the VO in astronomy, and world-wide web in everyday life (Chilingarian 2009a).

The most important feature of the VO should be the transparency of this infrastructure for a scientific user, who should be able to combine VO and non-VO stages while working on his/her research task.

2. Examples of VO-powered Research

In this section we present three projects where we study galaxy properties and evolution using Virtual Observatory technologies and tools. All these examples resulted in publications submitted or published in major refereed journals. For other examples of VO-powered research in Galactic astronomy see, e.g. Zolotukhin (2010) and Zolotukhin et al. (2010).

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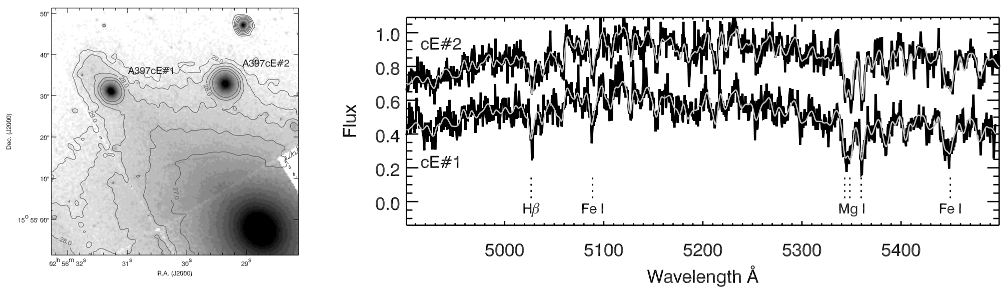

Figure 1. A fragment of a WFPC2 HST image of the central region of Abell 397 (left panel) with two candidate cE galaxies. The A397cE#1 candidate exhibits a prominent extended low surface brightness tidal feature toward the north-east. Optical spectra of these two galaxies obtained with 6-m telescope are shown in the right panel.

2.1. Search of Compact Elliptical Galaxies

Compact elliptical (cE) galaxies belong to a very rare class represented by only a handful of confirmed members (Mieske et al. 2005, Chilingarian et al. 2007a, Price et al. 2009), such as the Andromeda galaxy satellite M 32. They are characterised by small sizes (half-light radii $r_e \sim 0.1$ kpc) and high stellar densities, and thought to form through tidal stripping of massive progenitors, however, low statistics prevents us from making decisive conclusions. The compact morphology makes them unresolved for ground-based optical telescopes at a distances $>$50 Mpc. Using the superior image quality provided by the Hubble Space Telescope (HST) would allow us to push this limit to 200 Mpc, thus extending the volume of the Universe where we can detect them by a factor of 60.

We designed and implemented a workflow to search for candidate cE galaxies in large HST data collections provided by the Hubble Legacy Archive[1] and collect complementary information using VO resources in order to confirm or reject them. We first search for nearby clusters of galaxies ($z < 0.055$) using the CDS Vizier catalogue access service[2] and NASA/IPAC Extragalactic Database (NED)[3]. Then we use IVOA Simple Image Access Protocol to find and fetch HST images of the galaxy clusters from the HLA. Each image is then processed using SExtractor (Bertin & Arnouts, 1996) in order to detect galaxies, obtain their half-light radii and select compact objects with high surface brightness. At the last step we query NED, Vizier and a spectral database of Sloan Digital Sky Survey to find published redshifts or spectra of candidate objects.

Having applied the workflow to the HST WFPC2 data collection including images of 63 nearby galaxy clusters, in 26 of them we detected 55 cE candidates. For six of them we found archival SDSS DR7 spectra proving their membership in the clusters, and for eight were confirmed with the redshifts from literature.

[1] http://hla.stsci.edu/

[2] http://vizier.u-strasbg.fr/

[3] http://nedwww.ipac.caltech.edu/

Spectra of seven other candidates in three galaxy clusters were observed at the Russian 6-m telescope with the SCORPIO spectrograph (Fig 1).

By applying the NBursts full spectral fitting (Chilingarian et al. 2007b) to the available data for 13 galaxies, we determined velocity dispersions, ages and metallicities of their stellar populations. All galaxies turned to have high velocity dispersions and very old stars significantly more metal-rich than what is observed in dwarf galaxies of similar luminosities (see e.g. Chilingarian et al. 2008a, Chilingarian 2009b). All these properties suggested the tidal stripping of intermediate-luminosity galaxies as a way to create cEs. Similar situation is observed in ultra-compact dwarf galaxies (Drinkwater et al. 2003, Chilingarian et al. 2008b) and transitional objects (Chilingarian & Mamon 2008).

In order to prove this hypothesis, we ran dedicated numerical simulations of interactions of a disc galaxy with a galaxy cluster potential checking 32 different orbital configurations. Our simulations demonstrate the efficiency of tidal stripping in reducing the stellar mass of a disc galaxy on a timescale of 500–700 Myr by a factor of 2 to 10.

We converted the class of cE galaxies from "unique" into "common under certain environmental conditions" The full description of the workflow and the astrophysical interpretation of the discovery is available in Chilingarian et al. (2009a), the first VO-based paper published in an interdisciplinary journal.

2.2. FUV-to-NIR Properties of Low-Redshift Galaxies

We have cross-identified three large sources of photometric data: GALEX GR4 (UV), SDSS DR7 (optical), UKIDSS DR5 (NIR) and compiled a homogeneous FUV-to-NIR catalogue of spectral energy distributions of nearby galaxies ($0.03 < z < 0.6$). We have extracted the data for the spectroscopically confirmed galaxies and fitted their SDSS DR7 spectra to obtain stellar population parameters, velocity dispersion and residual emission line fluxes of some 200000 galaxies. By using VO tools and technologies, all the computational part of the study was completed in a week after the UKIDSS Data Release 5. More details of this project are given in Zolotukhin (2010). The first paper presenting the computation of k-correction, an essential step to construct multi-wavelength SEDs, is submitted to MNRAS.

2.3. The GalMer Database

The GalMer Database[4] is a library including thousands simulations of galaxy mergers at moderate resolution (0.2–0.3 kpc), made available to users through tools compatible with the Virtual Observatory (VO) standards adapted specially for this theoretical database. To investigate the physics of galaxy formation through hierarchical merging, it is necessary to simulate galaxy interactions varying a large number of parameters: morphological types, mass ratios, orbital configurations, etc. The GalMer database provides a reasonable compromise between the diversity of initial conditions and the details of underlying physics.

Apart from the direct access to simulations, we provide a set of value-added services which allow users to compare the results of the simulations directly

[4] http://galmer.obspm.fr/

to observations: stellar population modelling, dust extinction, spectra, images, visualisation using dedicated VO tools. They can be used as virtual telescope producing broadband images, 1D spectra, 3D spectral datacubes, thus making this database oriented towards the usage by observers.

The paper presenting the GalMer database as a VO resource is submitted to A&A. However, the analysis of GalMer simulations and modelling their stellar population properties have already been used to study the star formation efficiency in interactions (Di Matteo et al. 2007, 2008b), creation of old kinematically-decoupled systems (Di Matteo et al. 2008a), reshaping metallicity gradients in early-type galaxies (Di Matteo et al. 2009), and some simulations were found to match a complex observed light profile of a lenticular galaxy (Chilingarian et al. 2009b) proving its origin from a major merger.

3. Summary

These examples aim at stimulating usual astronomers to carry out VO-enabled research on everyday basis. We foresee a growing amount of VO-powered studies to arrive in near future.

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